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(71) Applicant(s)
The Minister of National Defence of Her Majesty's Canadian Government
(Incorporated in Canada)
101 Colonel By Drive, Ottawa KIA OK2, Canada

(72) Inventor(s)
Joseph Robert Jacques Bedard

(74) Agent and/or Address for Service
Graham Jones & Company
77 Beaconsfield Road, Blackheath, LONDON, SE3 7LG, United Kingdom

(54) Abstract Title
Active shaft-grounding system for ELF signature control

(57) In a ship or submarine grounding system for substantially eliminating the shaft-rate related alternating-field electromagnetic signature of the vessel, caused by the shaft-rate related modulation of the corrosion current, by maintaining the shaft at a fixed potential relative to the vessel's hull, the shaft-to-hull voltage is sensed at 19 and compared to a predetermined level and a current driver 28 provides a current at 20 from the propeller shaft to reduce the continuous voltage between the shaft and hull, the output current is biased so as to also reduce the bearing modulated shaft current, between the shaft and the hull, which is caused by the residual voltage between the shaft and the hull. A feedback loop biases the current driver so as to substantially eliminate the effects of semiconductor bias voltage on the shaft potential, thus maintaining the shaft at the desired potential over the operating range of the output current, and thus substantially eliminating the modulation of the shaft current and substantially eliminating the resulting electromagnetic signature.

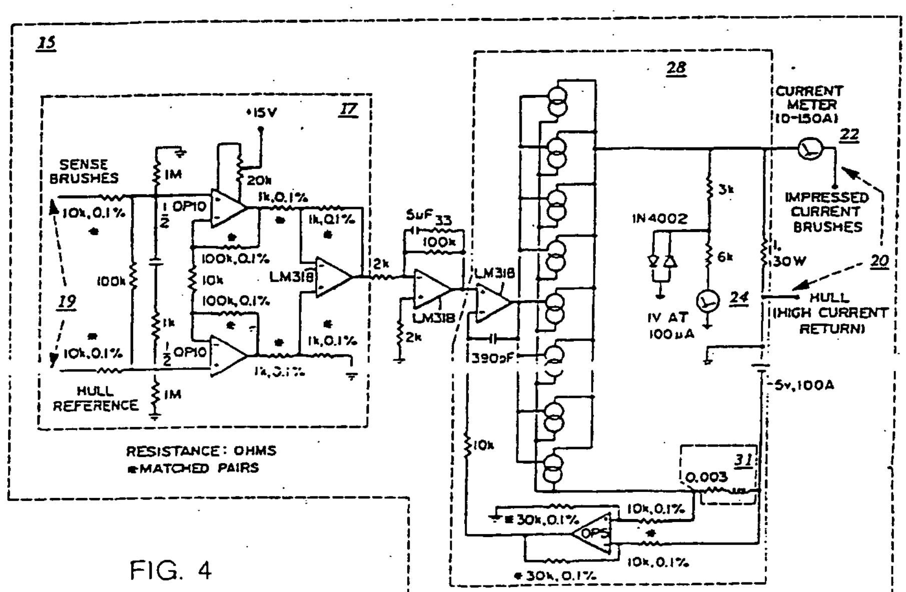

FIG. 4

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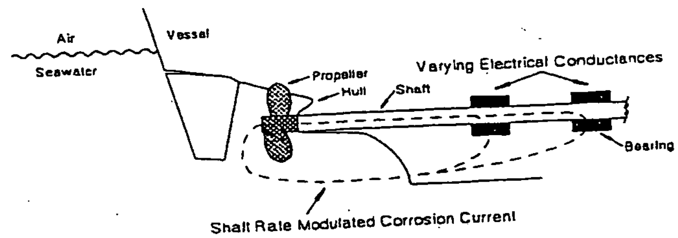


FIG 1a

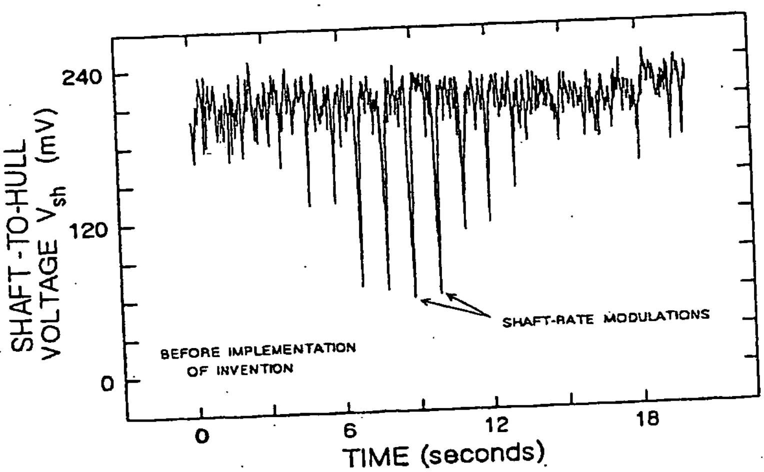


FIG 1b

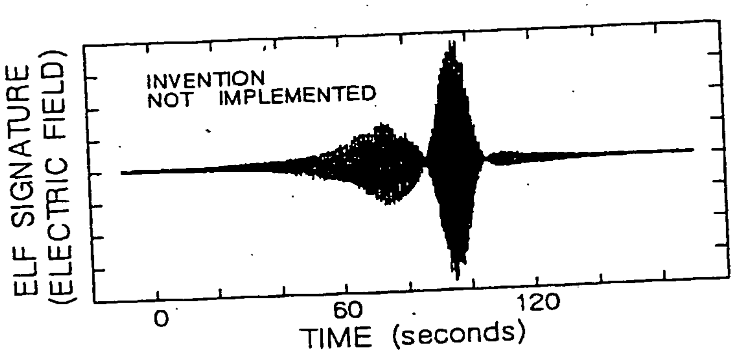


FIG 1c

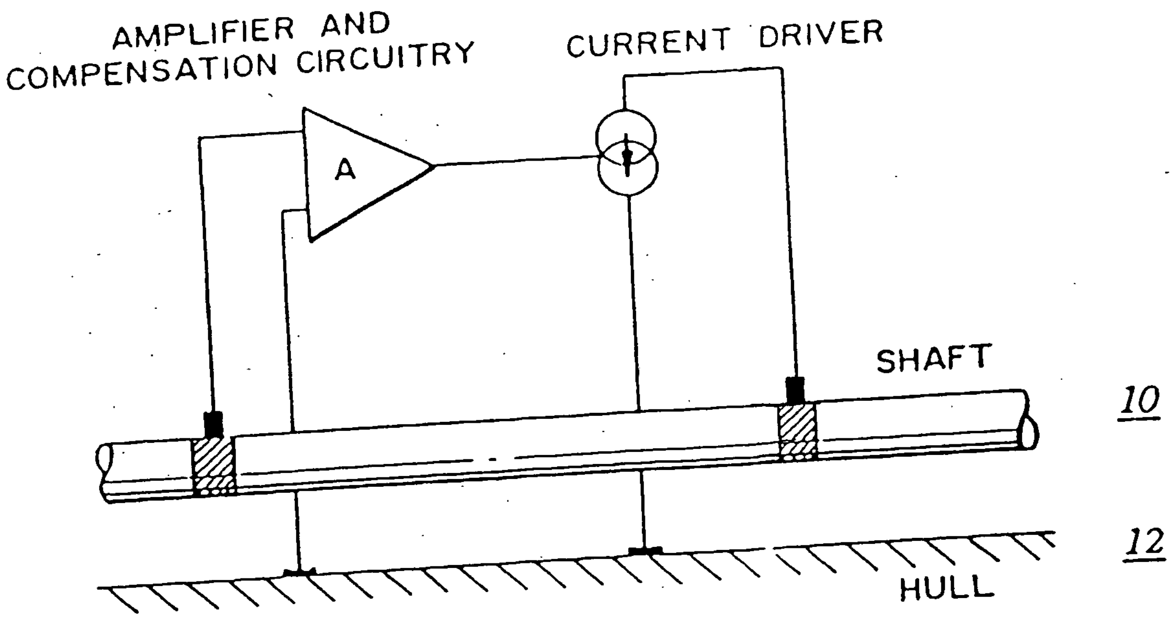

AMPLIFIER AND
COMPENSATION CIRCUITRY
CURRENT DRIVER
A
SHAFT
10
12
HULL

FIG. 2a

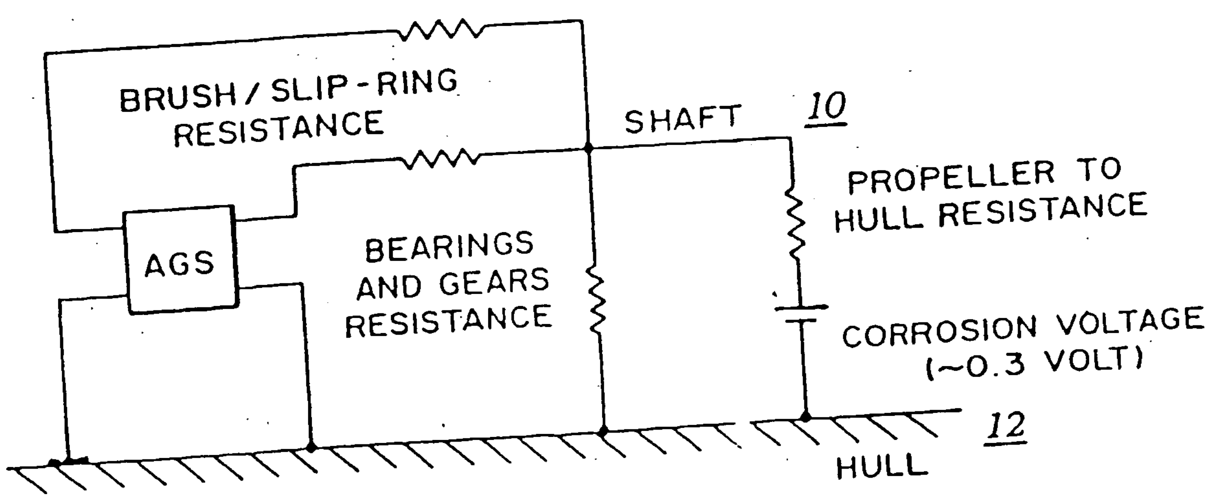

BRUSH / SLIP-RING
RESISTANCE
SHAFT
10
PROPELLER TO
HULL RESISTANCE
AGS
BEARINGS
AND GEARS
RESISTANCE
CORROSION VOLTAGE
(~0.3 VOLT)
12
HULL

FIG. 2b

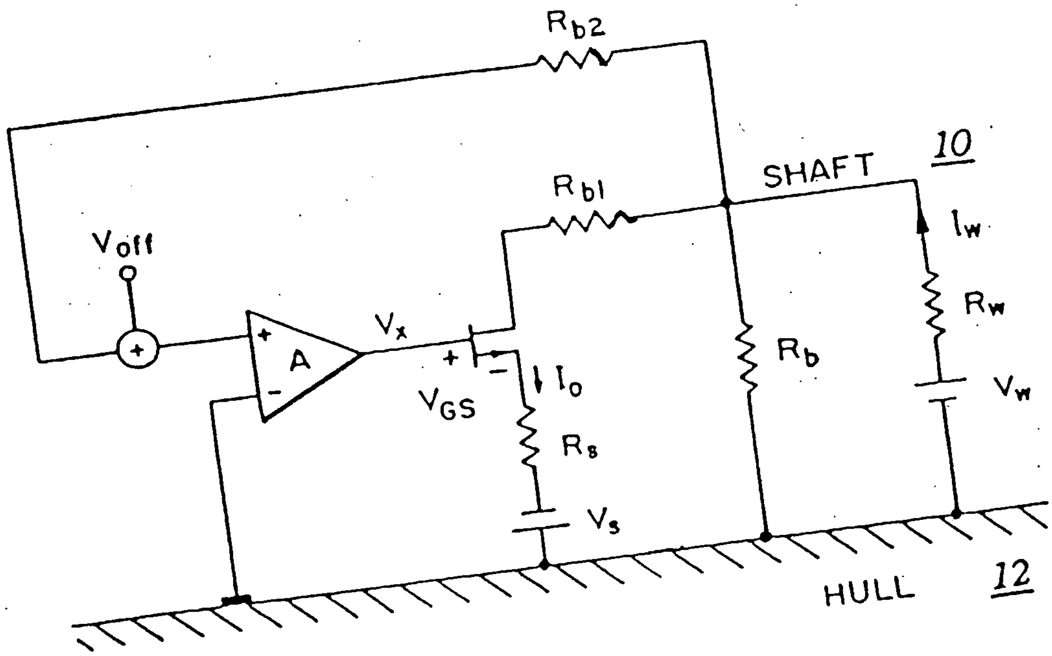
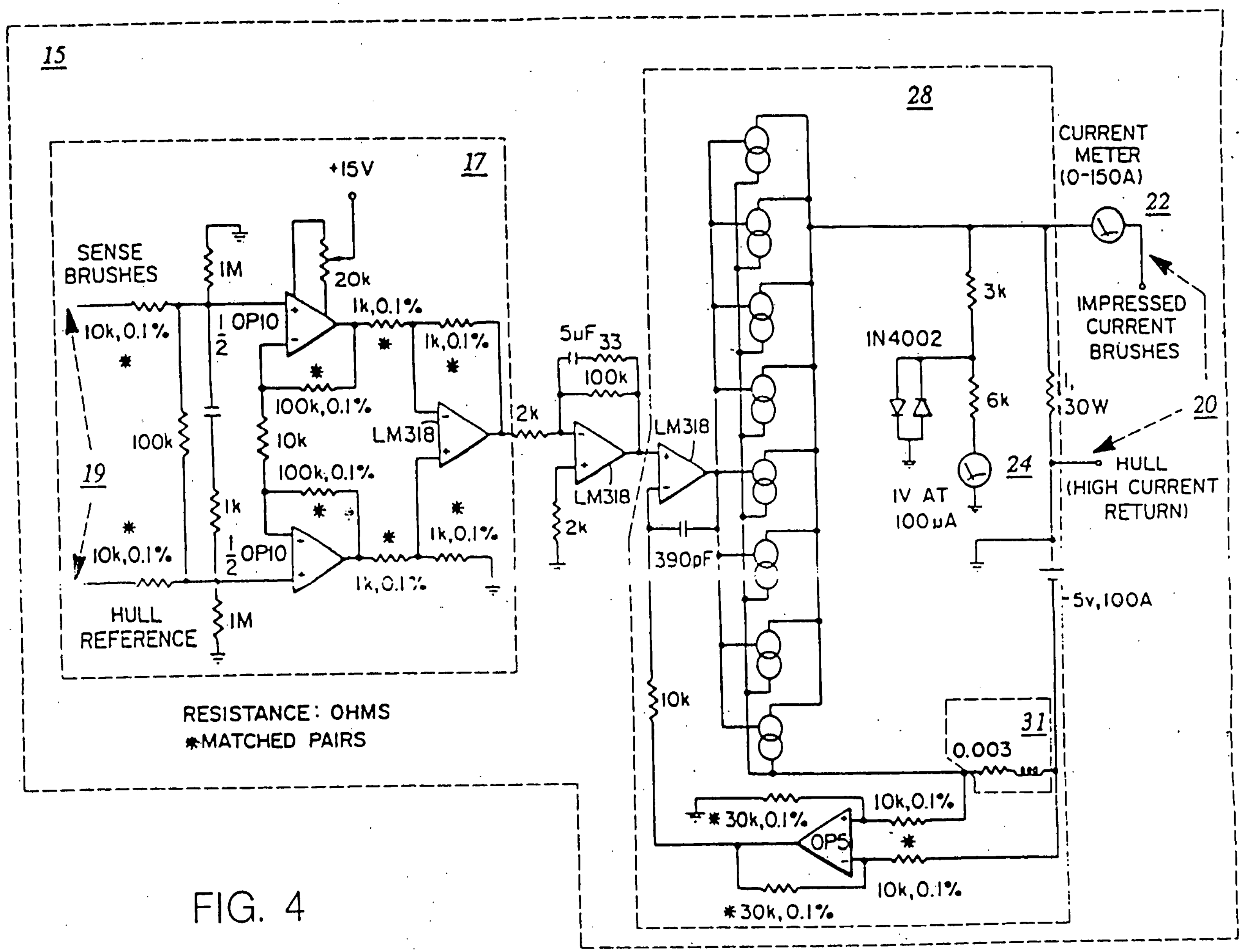
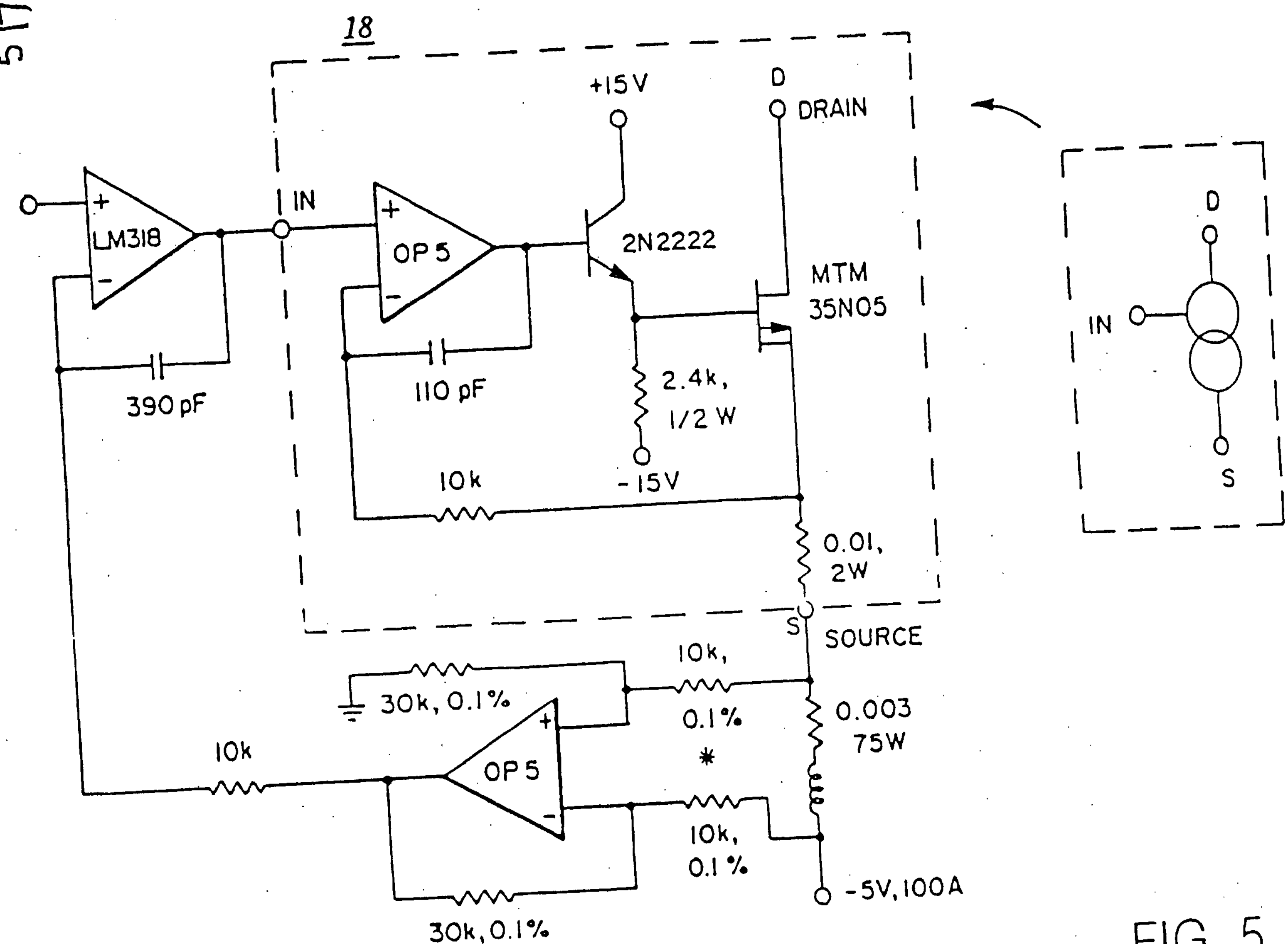


FIG. 3



15
17
+15V
SENSE BRUSHES
1M
20k
10k,0.1%
1/2 OP10
1k,0.1%
1k,0.1%
100k,0.1%
100k
10k
LM318
19
100k,0.1%
1k
1/2 OP10
10k,0.1%
1k,0.1%
1k,0.1%
HULL REFERENCE
1M
RESISTANCE: OHMS
*MATCHED PAIRS
5uF 33
100k
2k
LM318
LM318
2k
390pF
10k
28
CURRENT METER (0-150A)
22
IMPRESSED CURRENT BRUSHES
3k
1N4002
6k
1, 30W
20
24
HULL (HIGH CURRENT RETURN)
1V AT 100µA
-5v,100A
31
0.003
10k,0.1%
*30k,0.1%
OP5
10k,0.1%
*30k,0.1%

FIG. 4



RESISTANCE: OHMS

FIG. 5

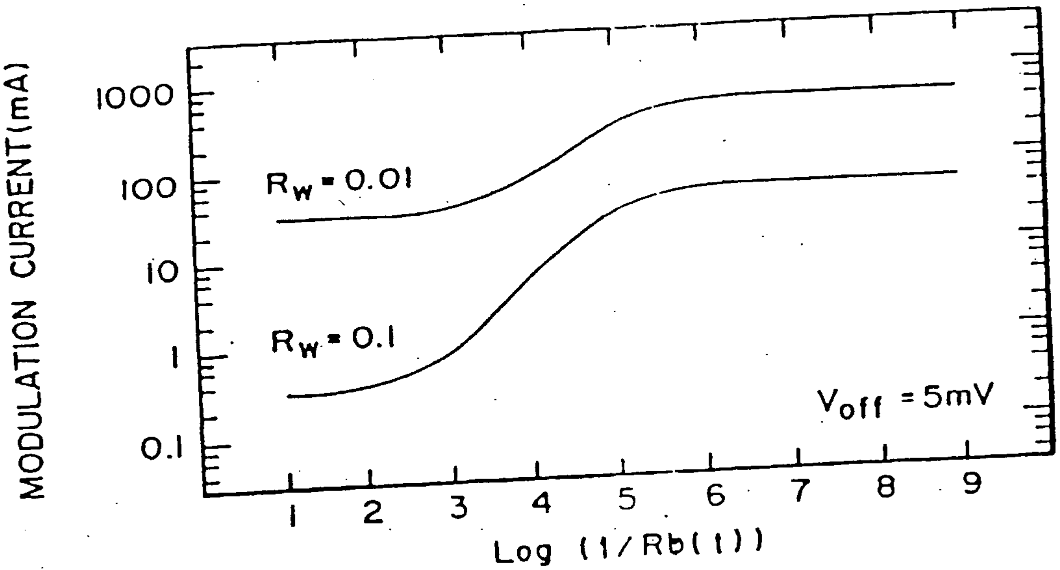

MODULATION CURRENT (mA)
1000
100
10
1
0.1
R_W = 0.01
R_W = 0.1
V_{off} = 5mV
1 2 3 4 5 6 7 8 9
Log (1/Rb(t))

FIG. 6a

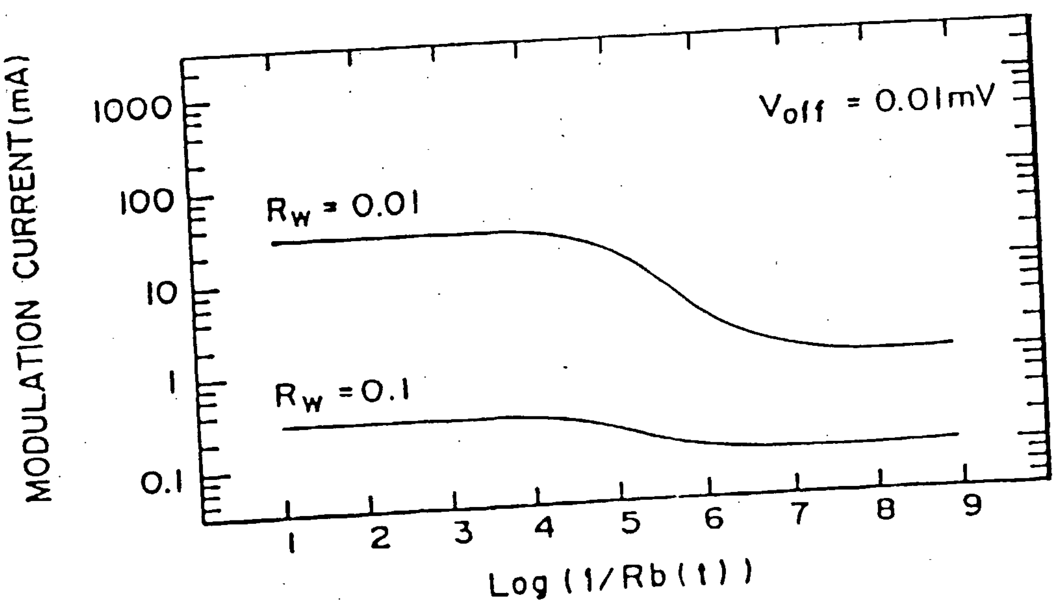

MODULATION CURRENT (mA)
1000
100
10
1
0.1
V_{off} = 0.01mV
R_W = 0.01
R_W = 0.1
1 2 3 4 5 6 7 8 9
Log (1/Rb(t))

FIG. 6b

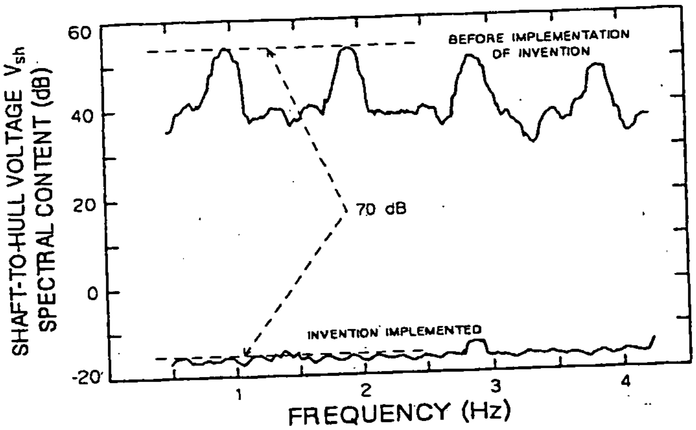


FIG 7a

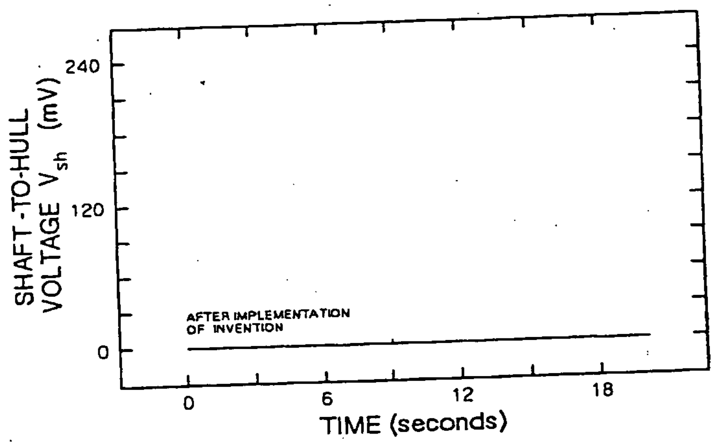


FIG 7b

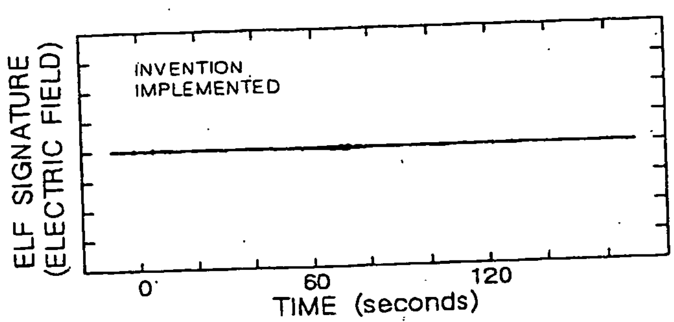


FIG 7c

BRIEF DESCRIPTION OF THE DRAWINGS

The typical prior known situation, and a preferred embodiment of the present invention will now be described in conjunction with the attached drawings, in which:

Figure 1a, 1b and 1c show a schematic diagram of the shaft-rate modulated corrosion current, the shaft-to-hull voltage difference, and the electromagnetic signature produced for a typical ship or submarine.

Figure 2a is a schematic diagram of an active grounding system, depicting its inter-connections to the shaft and the hull;

Figure 2b is a schematic diagram of an active grounding system, depicting the external parameters of the configuration;

Figure 3 is a simplified equivalent circuit diagram for the active grounding system of Figures 2a and 2b;

Figure 4 is a circuit diagram for the active grounding system of the present invention;

Figure 5 is a circuit diagram for the modular high current voltage driver of the active grounding system depicted in Figure 4;

Figures 6a,b graphically illustrate the functional relationship between the modulation current reduction and the bearing conductance;

Figures 7a,b,c graphically illustrate the effectiveness of the active grounding device in reducing the shaft-rate modulated current flowing in the shaft.

BACKGROUND OF THE INVENTION

In a typical situation, and as is known to people skilled in the art, the shaft-rate modulated current flow in the shaft and sea is as depicted in Figure 1a, the oscillating shaft-to-hull voltage is as depicted in Figure 1b, and a typical consequential ELF electromagnetic signature is as depicted in Figure 1c. For reduction of this ELF electromagnetic signature, an electrical bond between the shaft and hull, having an impedance about 10 times less than the propeller-to-hull resistance through the water, is sufficient. For many years, brush/slip-ring assemblies were used for this purpose. Although such assemblies provide reasonably adequate protection, daily monitoring is required to ensure that sufficiently low contact resistance is maintained. In ideal conditions, it has been shown that a factor of ten to fifteen reduction in signature can be obtained with passive grounding. But because this system is still not sufficient to reduce the signature to an acceptable level, active shaft grounding systems have been designed.

A controlled potential ship grounding system, disclosed in Canadian Patent No. 906,054, was designed to overcome the problem of maintaining a low resistance bond between the rotating shaft of a ship and the hull. Through a brush/slip-ring assembly, the described system senses the shaft-to-hull voltage, compares it to a predetermined level, and forces a current from the propeller-shaft to the hull in response to the difference. The reduction of the continuous voltage between the shaft and the hull results in a proportional reduction in the propeller-shaft corrosion current modulation and in the consequential ELF signature.

Although a system of the kind disclosed in the aforesaid patent provides a significant measure of decrease in signature, the reduction of the bearing modulated shaft current is limited. Thus, there is a need for an improved active shaft grounding system.

ACTIVE SHAFT-GROUNDING SYSTEM

FOR ELF SIGNATURE CONTROL

FIELD OF THE INVENTION

The present invention relates to a system for making non-detectable the shaft-rate modulated corrosion-current related alternating electromagnetic signature of a surface ship or submarine by controlling the potential of a rotating body, and more particularly relates to a system for controlling the potential of a rotating propeller shaft of a ship or submarine relative to the hull of the vessel, thereby substantially eliminating the fluctuations in the propeller shaft current that give rise to the radiating electromagnetic signature.

It is well known that a surface ship or submarine can be detected by the presence of its electromagnetic (EM) extremely low-frequency (ELF) signature, and that such a signature renders the vessel vulnerable to weapons systems utilizing EM influences. Because different metals are used in the fabrication of propellers (which are usually made of bronze) and hulls (which are usually made of steel), these parts of the ship, when in contact with sea-water, exhibit a voltage difference there-between of about 0.3 volts. On occasion, and for limited periods of time, the shaft-to-hull voltage can remain very stable at about 0.3 volts; this is attributed to a quasi-perfect electrical insulation between the shaft and the hull. In a typical situation, however, the bearings and gears electrically connect the shaft to the hull through a highly non-stationary impedance which is largely a function of the propeller shaft rotation, speed and load. This results in an alternating current in the water at the frequency of the shaft and at the harmonics of that frequency. This alternating current behaves as an oscillating electric dipole which radiates electric and magnetic fields. These oscillating fields form the major part of the so-called electromagnetic (EM) extremely-low frequency (ELF) signature of a surface ship or submarine, that is a cause of vulnerability, and which may be detected by naval mines, surveillance arrays, and other weapons systems that incorporate EM influences.

SUMMARY OF THE INVENTION

The present invention relates to a surface ship or submarine grounding system for controlling the shaft-rate modulated corrosion-current induced ELF signature of a vessel by maintaining the shaft at a fixed potential relative to the vessel's hull, in which the shaft-to-hull voltage is sensed and compared to a predetermined level and a current driver provides a current from the propeller shaft to reduce the continuous voltage between the shaft and hull, this output current being biased so as to also reduce the bearing modulated shaft current, between the shaft and the hull. A balanced impedance amplifier senses the shaft-to-hull voltage and controls a current driver which provides current to the rotating shaft, a feedback loop biasing the current driver so as to substantially eliminate the effects of semiconductor bias voltage on the shaft potential, thus maintaining the shaft at the desired potential over the operating range of the output current, and thus substantially eliminating the ELF signature.

More particularly, the present invention relates to an ELF signature suppression system arranged to control the electric potential of a rotating shaft for a vessel's propeller relative to the vessel's hull, comprising: sensing means arranged to sense the potential of the rotating shaft relative to a reference potential; current supply means arranged to cause a uni-directional flow of current to flow through a circuit including the rotating shaft; control means to control the flow of current from the current supply means through the circuit, the control means activating the current supply means in accordance with the output of the sensing means so as to maintain the potential of the shaft at the potential of the hull; the control means comprising a feedback loop such that an alternating current between the shaft and the hull caused by any residual voltage of the control means is substantially eliminated.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Figures 2a and 2b schematically depict a configuration of a typical active shaft grounding system, of a kind known to persons skilled in the art, Figure 2a depicting the inter-connections of the grounding system to a shaft 10 and a hull 12 of a vessel, and Figure 2b depicting the external parameters of the system. Figure 3 depicts a simplified equivalent circuit therefore. As shown in Figure 3, the voltage between shaft 10 and hull 12 is sensed through a set of brushes R_{b2} by a high impedance amplifier of gain A, designated thusly. For completeness, the amplifier offset voltage V_{off} is included. Amplifier output voltage V_x controls a high current transistor, which impresses current into shaft 10 through a set of brushes R_{b1}. The propeller-to-hull resistance through the water is represented by R_w, the value of which depends upon the water conductivity, the propeller bare metal area, and the turbulence present around the propeller; part of this resistance can also be attributed to the effect of the continuing corrosion process on shaft 10. For simplicity, R_w is assumed constant throughout the shaft revolution. The resistance of the bearings and gears R_b is largely a function of the propeller load, condition of the bearing to shaft contact, and rotation rate, and its value can change greatly during the shaft rotation. In Figure 3, V_w represents the propeller-to-hull galvanic voltage, V_s the power supply output voltage, and V_{gs} the transistor bias voltage.

From Figures 2a and 2b, and assuming the transistor transconductance to be infinite, the resulting propeller-shaft current is given by:

$$I_w = \frac{V_w}{R_w} + \frac{V_{off}}{R_w} - \left[\frac{\dfrac{V_w}{R_w} + \dfrac{V_{off}}{R_w} + \dfrac{V_{off}}{R_b} + \dfrac{V_{gs} - V_s}{R_s}}{1 + \dfrac{R_w}{R_b} + \dfrac{AR_w}{R_s}} \right] \qquad (1)$$

where, typically, $V_w = 0.3V$, $V_{off} \simeq 5mV$, $A = 10^4$, $0.01\Omega < R_w < 0.1\Omega$, $V_{gs} \simeq 3V$, $V_s = 5V$, and $0.01\Omega < R_s < 0.1\Omega$. The term V_w/R_w in relation (1) represents the propeller current under ideal shaft grounding conditions. The second term, V_{off}/R_w, is determined by the system offset voltage reference. The third term, between brackets in relation (1), is the residual voltage introduced by the finite gain of the system, and contains variations created by the bearings resistance fluctuations.

Although circuits of the type illustrated in Figure 2a and 2b provide some decrease in shaft-rate modulation of the current, the reduction is limited. As seen from relation (1) the modulation current is determined by essentially three sets of parameters. The first one consists of V_w, R_w and R_b, which are ship dependent. The second one is the grounding conductance of the system A/R_s, which ultimately sets the performances of the system. The last set consists of V_{off}, V_{gs} and V_s. Note that typically

$$V_{off} \simeq 5mV << V_W \simeq 0.4V \tag{2a}$$

$$(V_{gs} - V_s)\ \frac{R_W}{R_S} \simeq 4V >> V_W \simeq 0.4V \text{ and} \tag{2b}$$

$$V_{off}\ \frac{R_W}{R_S} >> V_W \text{ for } R_b << R_W \tag{2c}$$

It follows from relations (2b) and (2c) that if care is not taken in the way the current driver is designed, the residual current modulation reduction will be limited by the offset voltages V_{off} and $(V_{gs} - V_s)$, rather than by the vessel's parameters, at a given system grounding conductance A/R_s.

The present invention, depicted in Figures 4 and 5, eliminates the effect of the bias voltage $(V_{gs} - V_s)$, and lowers the reference voltage V_{off} to an insignificant level. V_{off} is considered negligible when

$$V_{off}\ \frac{R_W}{R_b} << V_W \ \Bigg|_{\ \frac{R_W}{R_b} \simeq \frac{A\ R_W}{R_S}} \tag{3a}$$

thus

$$V_{off} << \frac{R_S}{R_W A}, \quad (3b)$$

typically $V_{off} << 100\ \mu V$.

Similarly, the bias voltage (V_{gs} - V_S) can be neglected if

$$(V_{gs} - V_S) \frac{R_W}{R_S} << V_W. \quad (4)$$

To meet these design requirements, the circuit of the present invention must automatically bias the output current driver, and thus provide linear operation over the entire range of output current. To achieve this, a multi-feed back configuration is utilized. Instead of the high current transistor used in the system depicted in Figure 3, an internal current feedback loop is used in the present invention to remove the effect of the term represented by (V_{gs} - V_s) in relation (1), by automatically biasing the modular driver such that zero volts at its input gives zero amperes at its output. A voltage feedback loop ensures that the high current transistor is biased into its operating region. This configuration has the advantage of overcoming the problem of matching the the transistors. If a current larger than that available from a single high current transistor is needed, several stages can be added in parallel.

Similarly, the preset reference voltage, used in the ELF signature suppression system, is effectively set at zero. Figure 6 illustrates the effect of lowering the offset voltage, V_{off}, on the modulation current (that is, the term in brackets in relation (1)). Propeller-to-hull resistance (R_w) of 0.1Ω and 0.1Ω are plotted in Figure 6, these resistances representing the approximate limit of the range of value for R_w likely to be encountered on vessels. As shown in the aforesaid figure, for a maximum change in the bearing resistance, the modulation current varies from one plateau to another. By lowering the offset voltage, the upper conductance plateau is reduced, which diminishes the actual difference between the two plateaus. The transistor bias voltage, V_{gs}, and the power supply output voltage, V_s, are set to zero for the calculation.

The circuit diagram of the present invention, the system generally being designated as 15, is depicted in Figure 4. System 15 consists of a voltage-controlled current driver 28 preceded by a differential voltage amplifier 17. Current driver 28 comprises eight voltage drivers, 18, placed in parallel, in a current feedback loop. Figure 5 illustrates the circuit for voltage driver 18A, the other drivers 18 being identical. These other drivers 18 are stacked at the points IN, D(drain), and S(source), as shown in Figure 5. This multi-feedback approach allows the high current Field Effect Transistors (FET) of voltage drivers 18 to safely be placed in parallel. The 0.01Ω resistance is included to limit the current differences between the FET's to a maximum of 100 mA. Differential amplifier 17 ensures impedance matching between the two inputs.

The operational amplifiers used in system 15 were chosen to optimize the performances and minimize the number of adjustments on the device. The LM318 amplifiers were used at points where the noise and offset voltage were not critical, so as to minimize the loss in bandwidth. The OP-10 and OP-5 amplifiers were used at the input of system 15 because of their low noise and low offset voltage; in voltage drivers 18, because of their low offset voltages, which limits the static current between the FET's; and in the current sensing amplifier, to minimize noise. (The output current is sensed through a 3 mΩ resistance which develops voltages comparable to the input noise voltage of a LM318 amplifier at low current.)

The frequency compensation of system 15 is an important step which has a significant effect on the overall performance of the grounding configuration. System 15 impresses a current as a result of a voltage control. This current couples to the propeller-to-hull impedance and creates a voltage that is then fed back to the input. The propeller-to-hull impedance (R_w in Figure 3) is part of the feedback loop, and must be known in order to stabilize system 15. As indicated previously, the real part of the impedance ranges from 0.01Ω to 0.1Ω, depending upon the propellers used, and as a safety measure, the largest value of 0,1Ω should be assumed, since this

ensures stability at the highest possible voltage gain. Furthermore, a 0.1Ω resistance is added at the output of the device (as illustrated in Figure 4) to keep the output impedance below 0.1Ω if the brush/slip-ring resistance becomes large.

In principle, the stability of system 15 is achieved by reducing the open loop gain to unity or less, at frequencies at which the phase is greater or equal to 180 degrees. As shown in Figure 5, each individual element 18 of current driver 28 is compensated by a 10 KΩ resistor R_c and a 10 pF capacitor C_c before compensation is carried out on the overall system. An extra stage 30 is added for this purpose, and placed between the output current driver and instrumentation amplifier 17. This stage enables wide band over-amplification of the input signal, which often saturates preamplifier 17 with undesirable high frequency signals, to be avoided. An inductor 31 is also included in the output current feedback loop so as to allow for the propeller-to-hull inductance. Inductor 31 enables over-compensation of the unit to be avoided and prevents undesirable oscillations.

The overall physical layout of system 15 is dictated by power consumption considerations. The modular output is preferably arranged so that the FET of each of eight voltage drivers 18 will draw an equal current. If the system 15 device is driven to its maximum current, 100 A, the current in each FET will be 12.5 amperes and the combined power consumption will be at most 62.5 watts. A standard switching power supply (not herewith depicted) of 100 amperes, five volts, is used for system 15.

Three sets of wires are connected to the case containing system 15. A first twisted pair of wires (not shown), the power line which supplies up to five amperes, should be routed as far as possible from the other conductors in order to reduce 60 Hz pick up. A second shielded twisted pair of wires 19 is used for sensing the potential between shaft 10 and hull 12. These conductors may be any convenient size, since the line impedance is greater than 100 KΩ. A third pair of large wires 20 carries the current from

shaft 10 and returns it to the hull. The total resistance of wires 20 should be chosen such that the voltage drop is insignificant compared to five volts, less than 0.2 volts at 100 amperes being acceptable. Lengths of No. 4 conductor wire can be used for this purpose.

Three meters are required to monitor the operation of system 15. One meter (not herewith depicted) indicates the operating shaft potential in tenths of millivolts. The output of system 15 is indicated by a second meter 22, and the condition of the current connection to shaft is shown by a third meter 24, which measures the output voltage of current driver 28 (also known as the grounding voltage). If this latter voltage becomes greater than 0.5 volts, cleaning of the slip-ring may be necessary. If this fails to reduce the grounding voltage, then the continuity of the current carrying wires and the slip-ring to shaft contact resistance must be checked.

EFFECTIVENESS OF THE INVENTION

Evidence of the effectiveness of the present invention in reducing the shaft-rate modulated current that flows through the shaft and propeller into the sea-water, thus giving rise to the vessel's signature, will now be described for a particular implementation of the invention using the foregoing preferred embodiment.

In the absence of an active shaft-grounding system, the shaft-to-hull voltage of a typical vessel was measured and was as depicted in Figure 1b, and by using Fourier Transform spectral analysis techniques was found to have the large variations depicted in the upper traces of Figure 7a for the shaft-rate frequency and its first few harmonics. When the active grounding system described in the present invention was implemented, the results of the lower trace of Figure 7a were obtained, showing a reduction in modulation of in excess of 70 dB, and the corresponding shaft-to-hull voltage being as depicted in Figure 7b. As the measure of the modulated shaft-to-hull voltage is directly proportional to the magnitude of the shaft-rate modulated

corrosion-current induced ELF electromagnetic signature, the signature is also reduced by in excess of 70 dB. When the present invention was implemented on the typical vessel for which the signature was as depicted in Figure 1c, the signature is substantially eliminated as depicted in Figure 7c.

The foregoing has shown and described a particular embodiment of the invention, and variations thereof will be obvious to one skilled in the art. Accordingly, the embodiment is to be taken as illustrative rather than limitative, and the true scope of the invention is as set out in the appended claims.

CLAIMS

1. An ELF electromagnetic signature suppression system arranged to control the electric potential of a rotating shaft for a surface ship or submarine's propeller relative to the ship's hull, comprising:

sensing means arranged to sense the potential of said rotating shaft relative to a reference potential;

current supply means arranged to cause a unidirectional current to flow through a circuit including said rotating shaft;

control means to control said flow of current from said current supply means through said circuit, said control means actuating said current supply means in accordance with the output of said sensing means so as to maintain the potential of said shaft at the potential of said hull;

said control means comprising a feedback loop such that an alternating current between said shaft and said hull caused by any residual voltage of said control means is substantially eliminated.

2. The ELF electromagnetic signature suppression system of claim 1, wherein said reference potential is the potential of said hull.

3. The ELF electromagnetic signature suppression system of claim 1 or 2, wherein said sensing means comprises a balanced impedance amplifier having as an input an electrical contact engaging said rotating shaft, and having an input impedance sufficiently large to reduce the current flow through the electrical contact substantially to zero.

4. The ELF electromagnetic signature suppression system of claim 1, wherein said current supply means is a current driver comprising a plurality of parallel low output-impedance voltage drivers in a current feedback loop.

5. The ELF electromagnetic signature suppression system of claim 4, wherein said current driver is preceded by a differential voltage amplifier.

6. A system for reducing the modulated current produced by a rotating shaft of a ship, comprising:

sensing means arranged to sense the potential of said rotating shaft relative to the hull of said vessel;

current supply means arranged to cause a unidirectional current to flow through a circuit including said rotating shaft;

control means to control said flow of current from said current supply means through said circuit, said control means actuating said current supply means in accordance with the output of said sensing means so as to maintain the potential of said shaft at the potential of said hull;

said control means comprising a feedback loop such that an alternating current between said shaft and said hull caused by any residual voltage of said control means is substantially eliminated.

7. An ELF electromagnetic signature suppression system according to claim 1 and substantially as herein described with reference to the accompanying drawings.

8. A system of reducing the modulated current produced by a rotary shaft of a ship, according to claim 6 and substantially as herein described with reference to the accompanying drawings.

Amendments to the claims have been filed as follows

1. An ELF electromagnetic signature suppression system arranged to control the electric potential of a rotating shaft for a surface ship or a submarine's propeller relative to a reference potential, comprising:

sensing means arranged to sense the potential of said rotating shaft relative to said reference potential;

current supply means arranged to cause a unidirectional current to flow through a circuit including said rotating shaft;

control means to control said flow of current from said current supply means through said circuit, said control means actuating said current supply means in accordance with the output of said sensing means so as to maintain the potential of said shaft at the potential of said reference potential;

said control means comprising a feedback loop such that any alternating current between said shaft and said reference potential is substantially eliminated.

2. The ELF electromagnetic signature suppression system of claim 1, wherein said reference potential is the potential of the hull of the surface ship or the submarine.

3. The ELF electromagnetic signature suppression system of claim 1 or 2, wherein said sensing means comprises a balanced impedance amplifier having as an input an electrical contact engaging said rotating shaft, and having an input impedance sufficiently large to reduce the current flow through the electrical contact substantially to zero.

4. The ELF electromagnetic signature suppression system of claim 1, wherein said current supply means is a current driver

comprising a plurality of parallel low output-impedance voltage drivers in a current feedback loop.

5. The ELF electromagnetic signature suppression system of claim 4, wherein said current driver is preceded by a differential voltage amplifier.

6. A system for reducing the modulated current produced by a rotating shaft of a ship, comprising:

sensing means arranged to sense the potential of said rotating shaft relative to a reference potential;

current supply means arranged to cause a unidirectional current to flow through a circuit including said rotating shaft;

control means to control said flow of current from said current supply means through said circuit, said control means actuating said current supply means in accordance with the ouput of said sensing means so as to maintain the potential of said shaft at the potential of said reference potential;

said control means comprising a feedback loop such that any alternating current between said shaft and said hull is substantially eliminated.

7. An ELF electromagnetic signature suppression system according to claim 1 and substantially as herein described with reference to the accompanying drawings.

8. A system of reducing the modulated current produced by a rotary shaft of a ship, according to claim 6 and substantially as herein described with reference to the accompanying drawings.

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Patents Act 1977
·aminer's report to the Comptroller under Section 17 (The Search Report)

Application number

892772

Relevant Technical fields

(i) UK Cl (Edition J) G3U: UC, UEF, VAX

(ii) Int Cl (Edition 4) G05F

Databases (see over)

(i) UK Patent Office

(ii) ONLINE DATABASES: WPI, CLAIMS, INSPEC

Search Examiner

G A McLEAN

Date of Search

12 JUNE 1990

Documents considered relevant following a search in respect of claims 1 - 8

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
X	CA 906,054 (DEFENCE) - as acknowledged in the application; especially lines 32-39, page 1; lines 8-54, page 2; figures 1 - 3	1 - 6

SF2(p)